eRD1 Update. Some effects of Rad Damages on SiPM performance.

Jan. 24 , 2019

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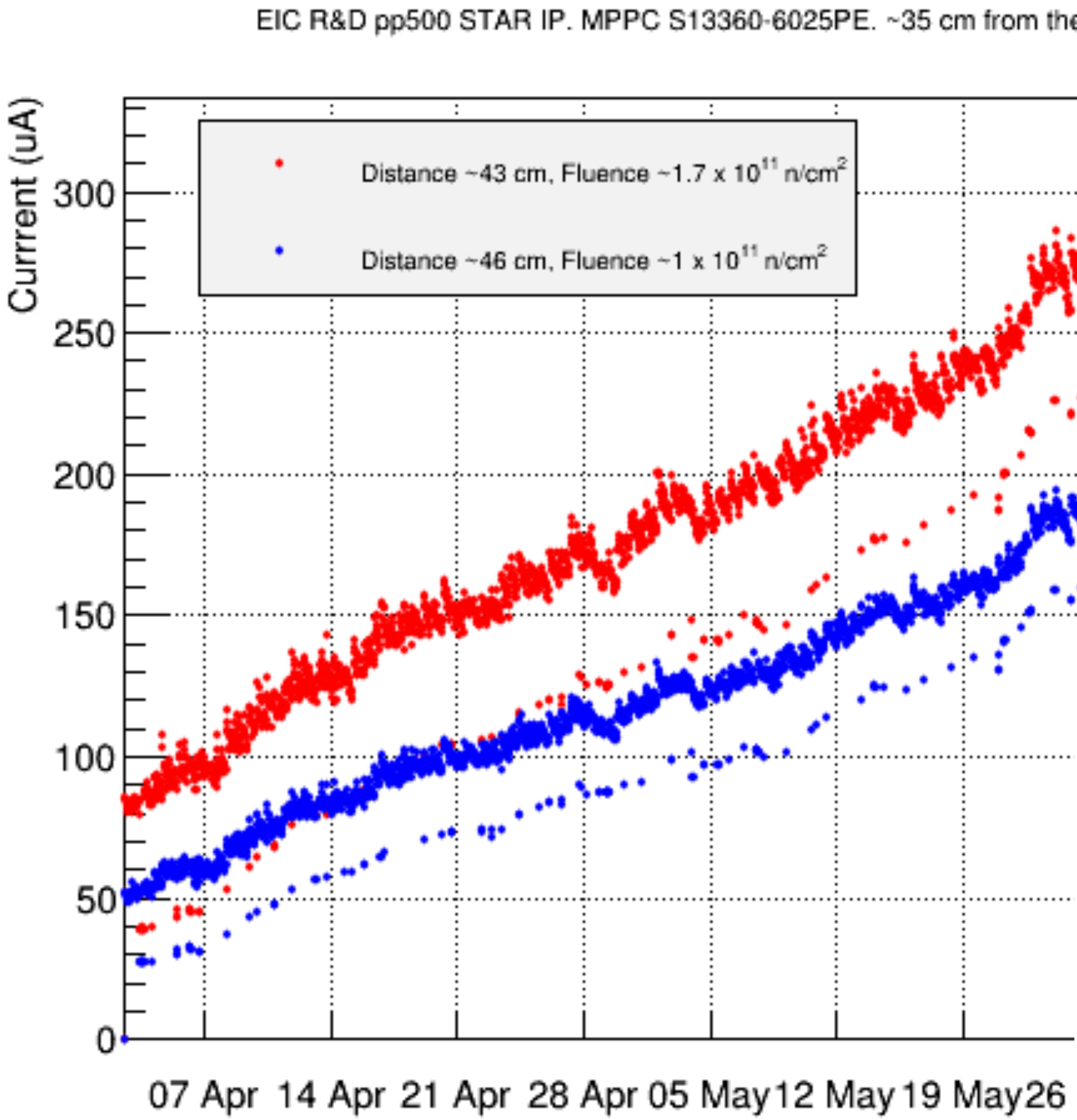
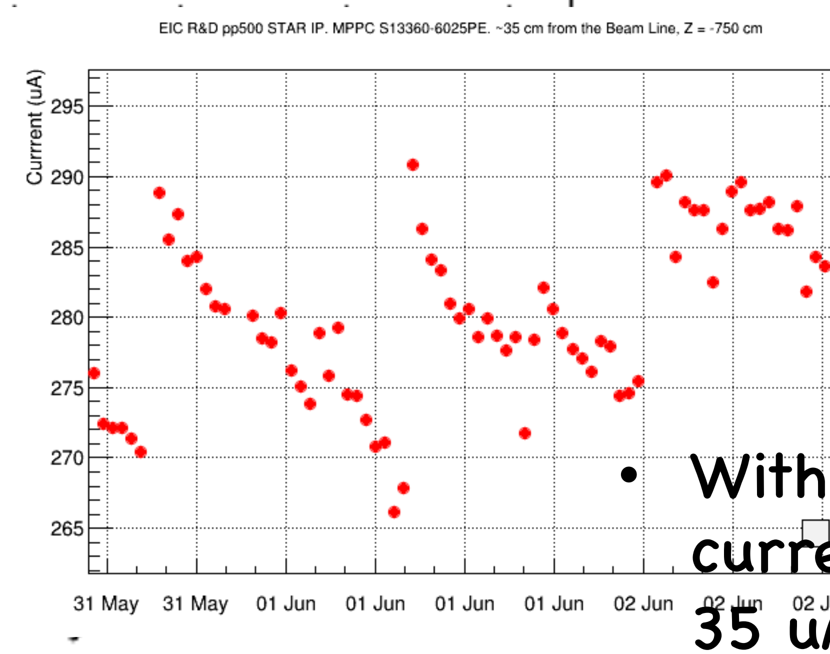
- Run 17. Conditions at STAR Forward close to what will be at EIC.



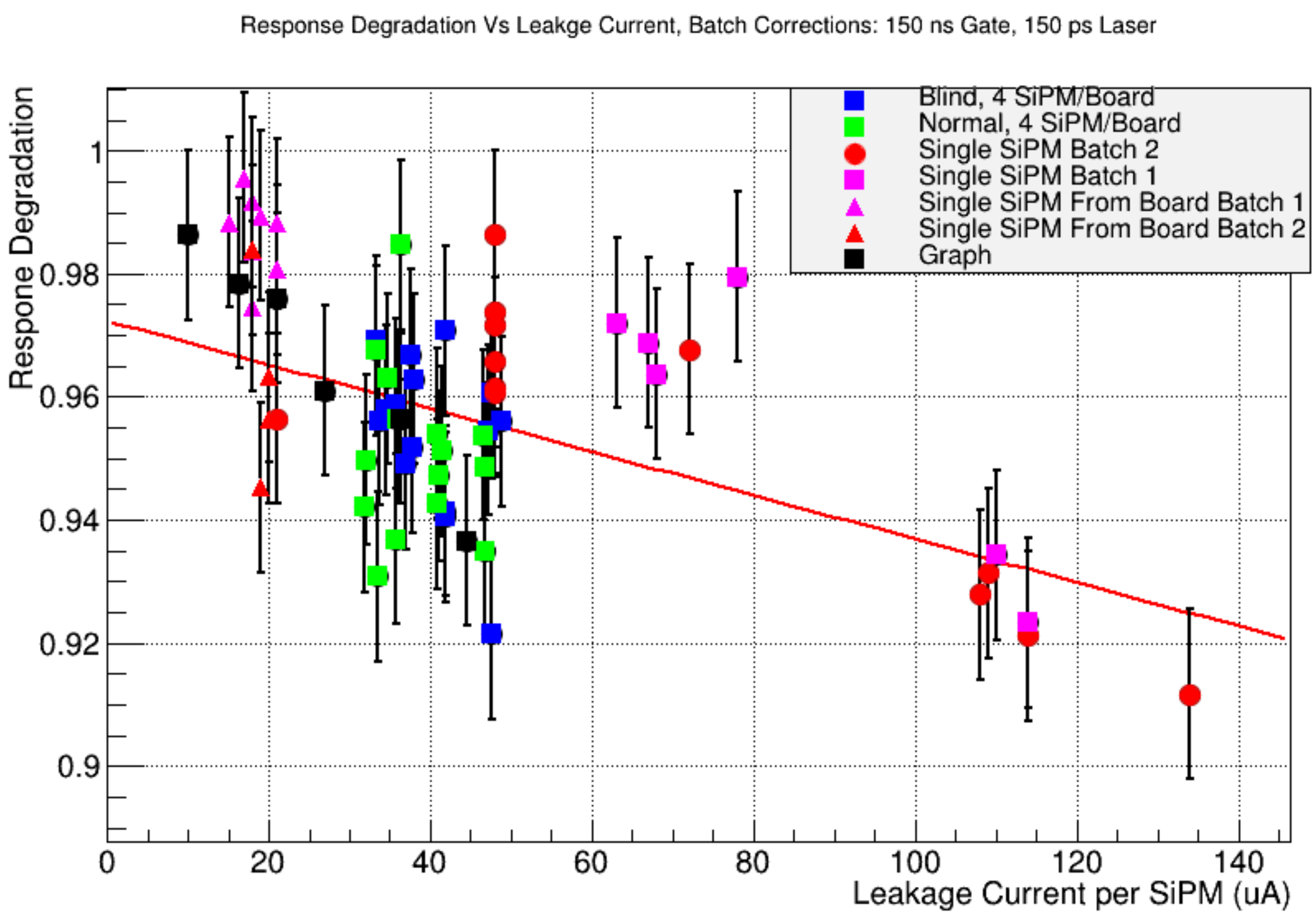
- Strong dependence on location.
- Shielded/ unshielded by nearby EM blocks



- Within one fill current changes ~ 35 uA

- These are for 36 mm^2 SiPMs. For 3 x3 mm current will be about 100 uA at the end of the run.
- Gain was set ~ 3x10^5, Overvoltage 2.14V

- SiPMs, exposed in Run 17 – degradation of response caused by shift in Vbd. Reasons for changes of Vbd was not immediately clear.
- SiPM, exposed in Run 18, exposure is too low (1/20 Run 17), no changes in response observed.
- More studies performed by UCLA students to investigate reason for shift in Vbd.



~ Eta 2.5

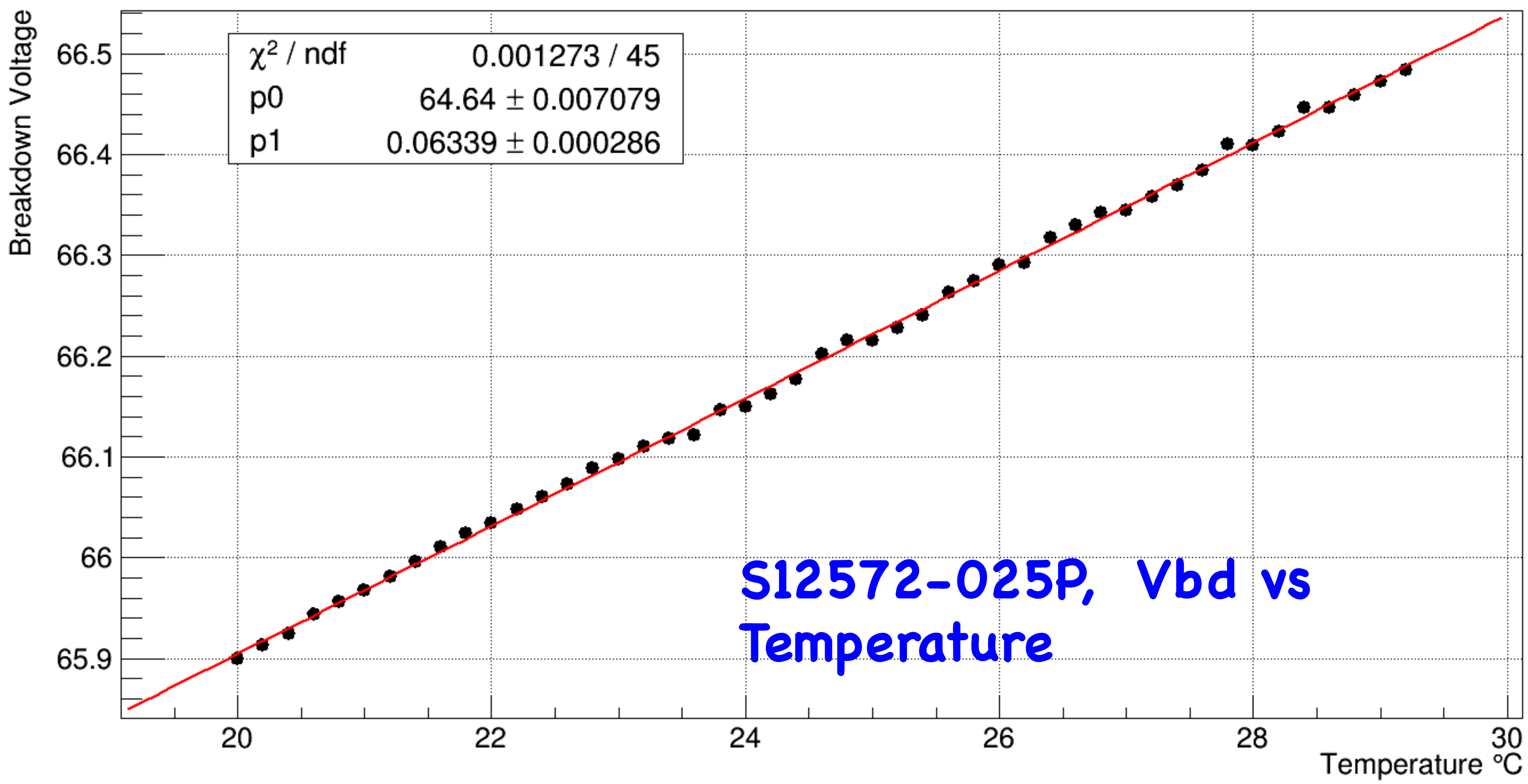
~ Eta 4

- 3 x 3 mm^2 SiPMs
- Run 17.
- Location spans Forward Calorimeter Area

Two effects:

- **Overall slope**
- **Dispersion**

Search in literature did not provide clear clues. Dopant changes and destruction of 10% individual pixels pixels with exposure ruled out.

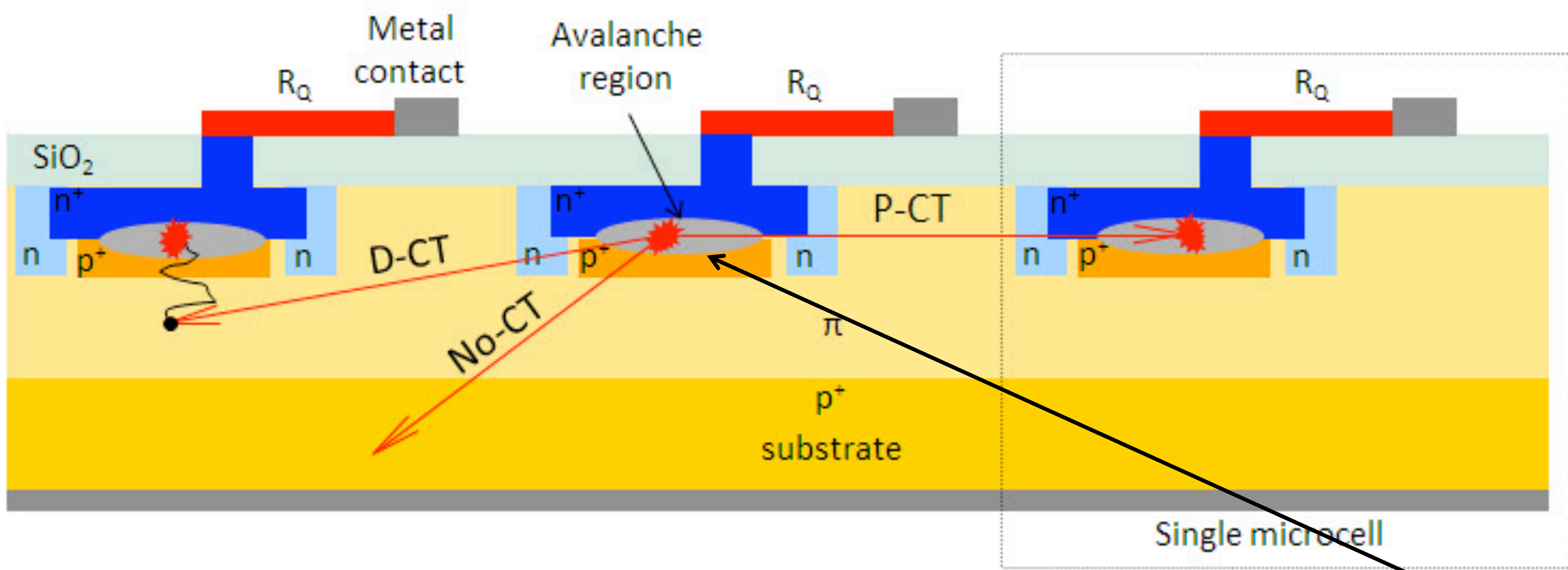


- Vbd changes
- ~ 60 mV/C
- As measured in T controlled chamber in 2017
- (slow heating, 8 hours data taking)

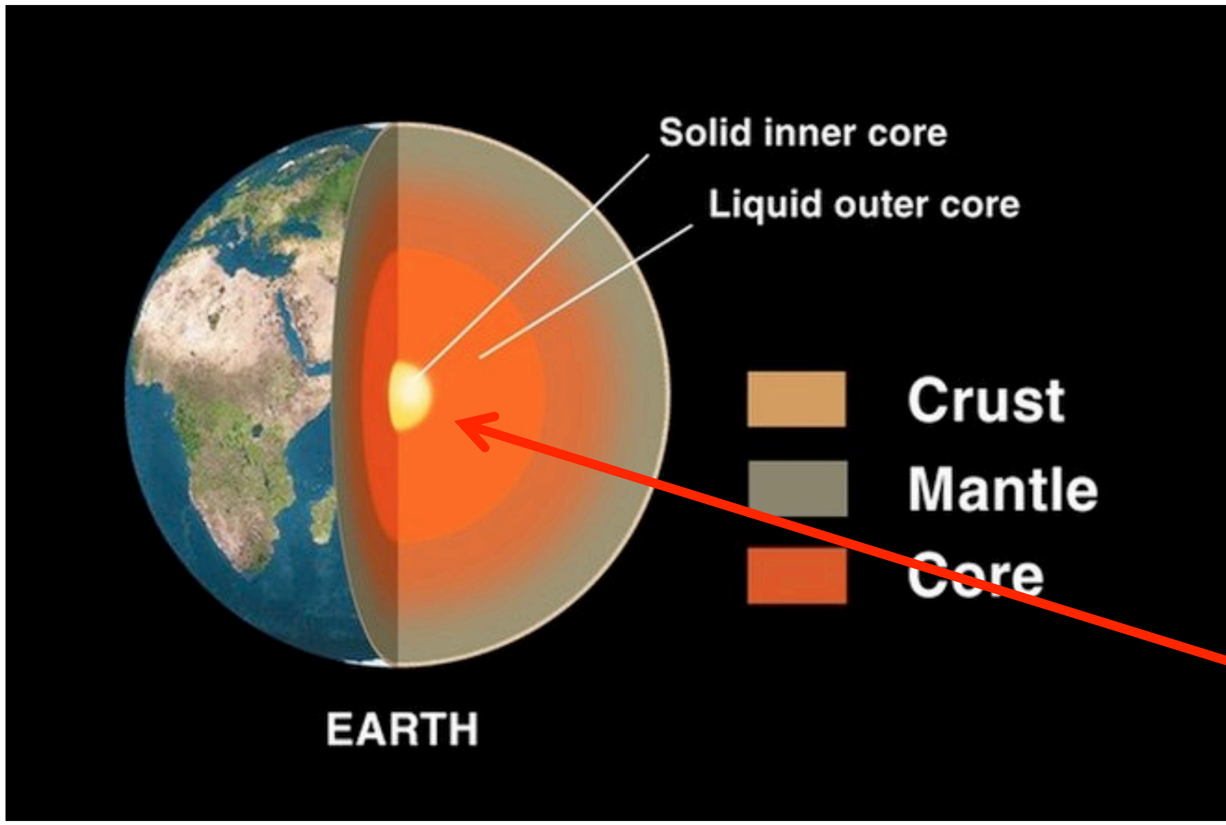
Tricky question "What T is it?"

2018. Developed methodic to verify local junction heating suspicion.

- 'Preheat' SiPM with constant illumination by LED to mimic conditions at experiment (current on Slide 2).
- Then quickly measure Vbd or Response with dimmed light to see how they changes with time, i.e. during cooling of junctions back to ambient T.



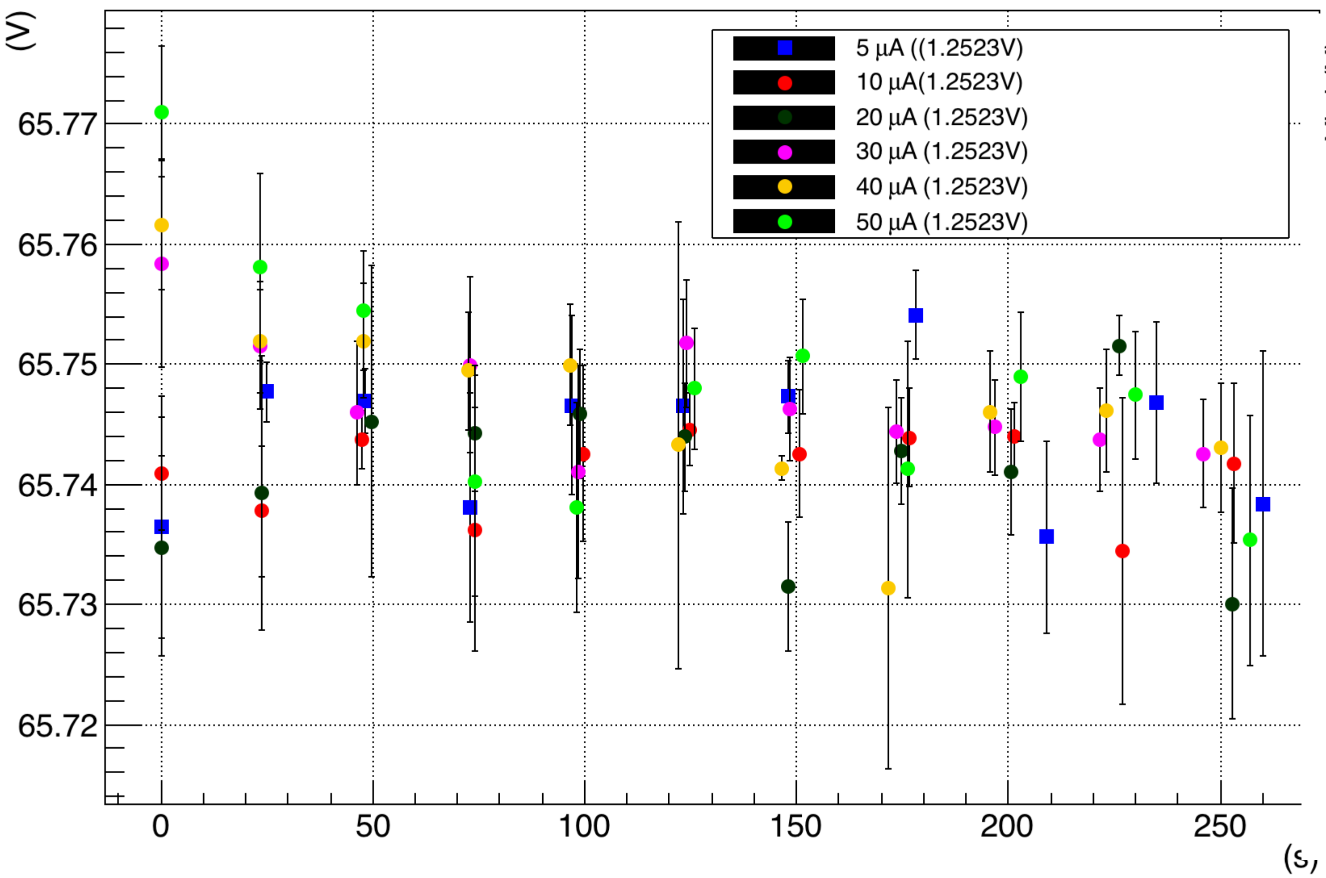
What is T over there
at experimental conditions?
(exposure + signal current)

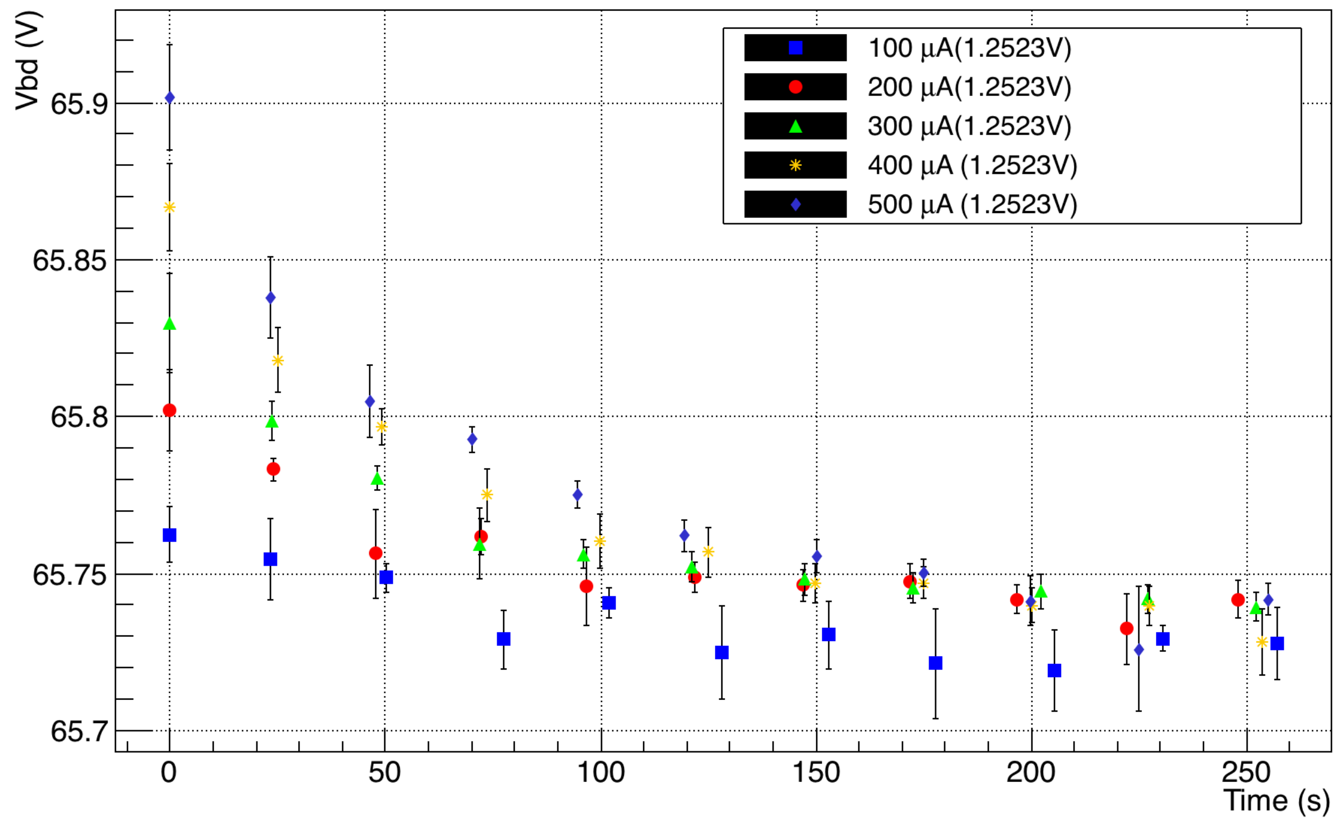


Estimated T ~ 6000 C

Estimated @10 MHz dark noise, 5 um thick layer, 5V overvoltage, no heat dissipation. T rises ~1 deg/sec

Vbd vs Time. Cool down Starts at 0.



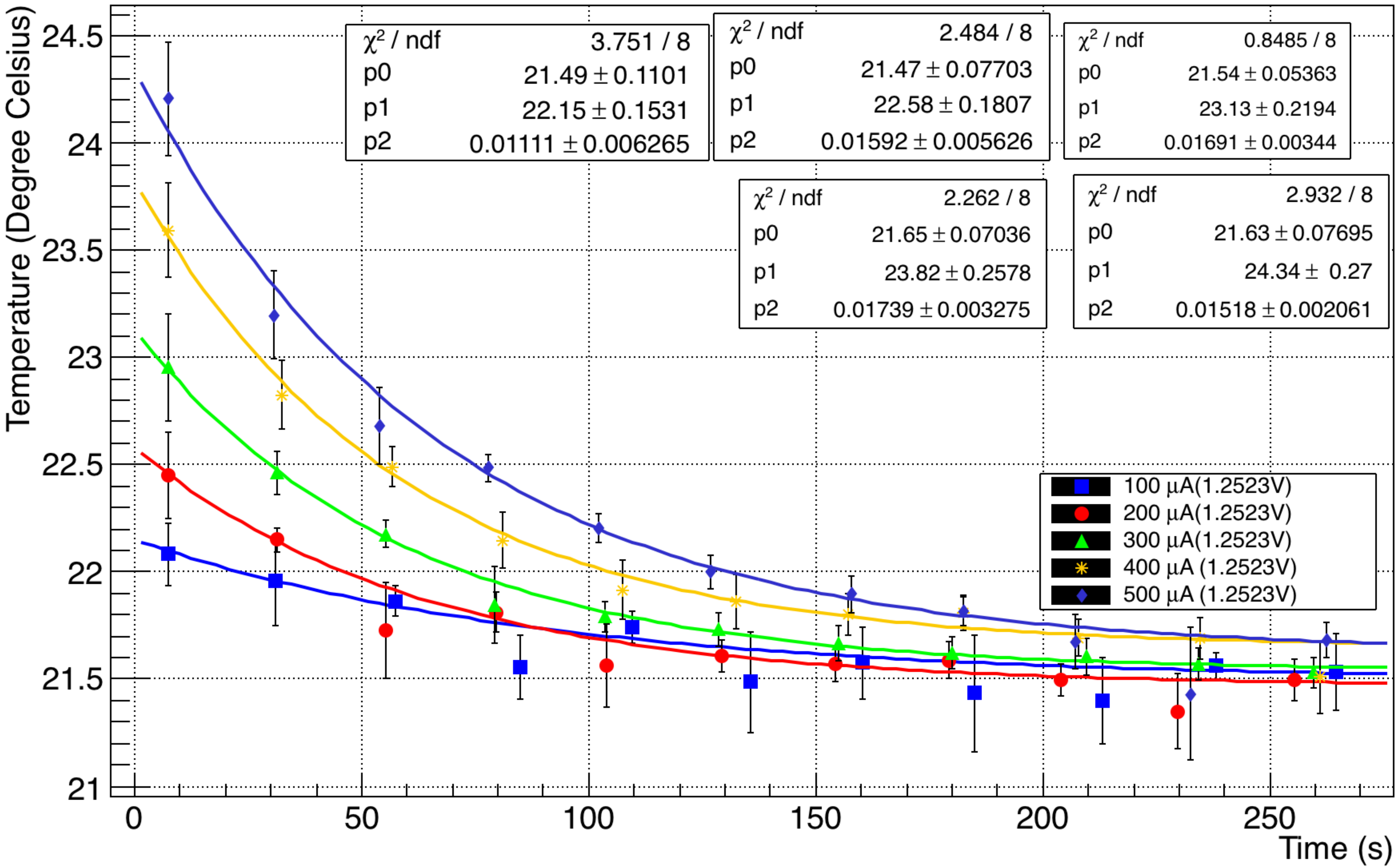


SiPM kept 5 min at highets over votage for IV scan (1.25V) with specified current, then series of IV scans taken.

'Preheating' with 30-40 uA current – already shows hints that Vbd changes.

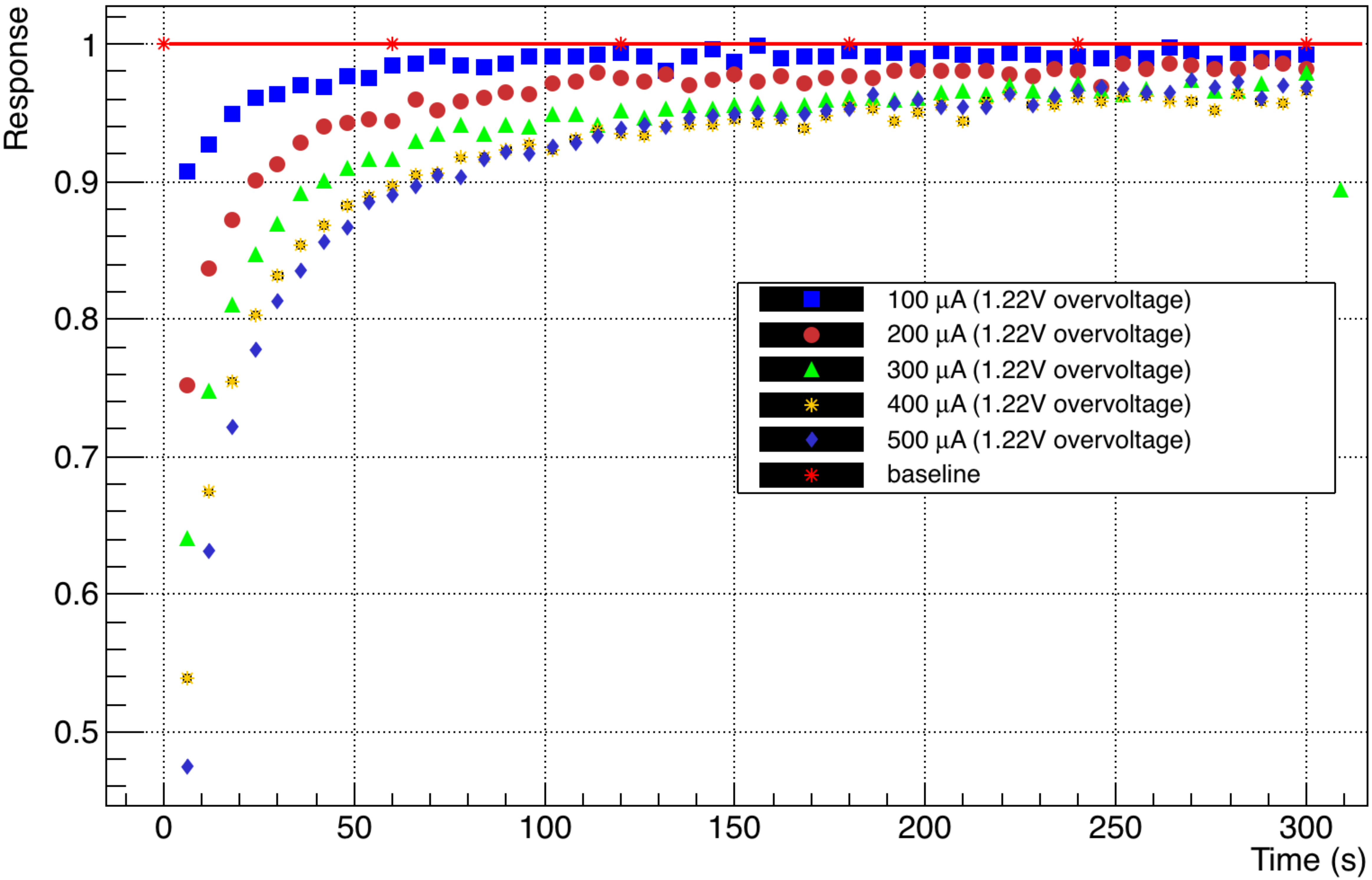
- SiPM kept 5 min at highest over voltage for IV scan (1.25V) with specified current. HeatUp

- IV scans taken with 20uA highest current. Cooldown.

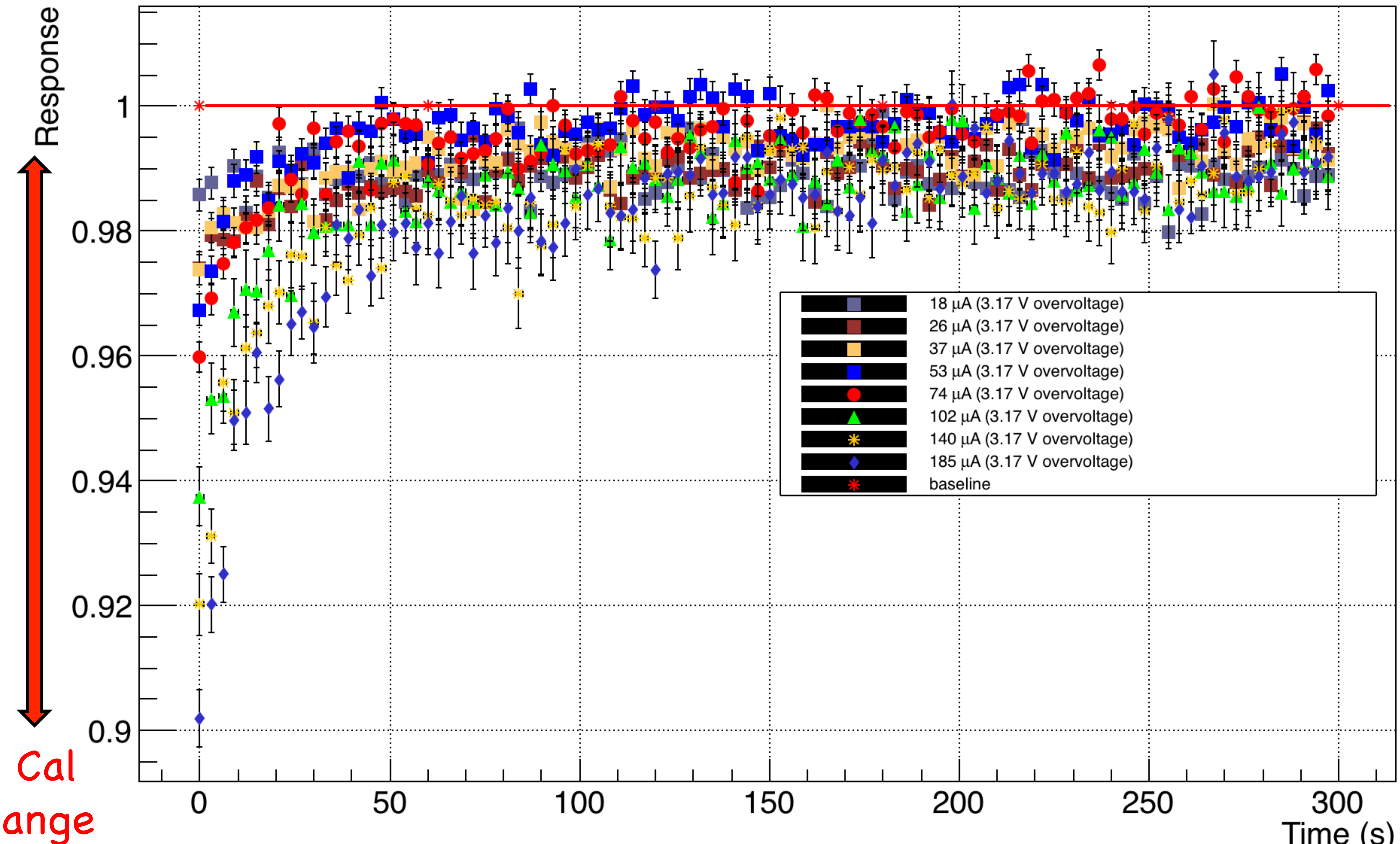


- Knowing Vbd vs T (slide 4) we can calculate T in junction vs time.
- Fit with Newton's law of cooling (p1 – junction temperature at t=0, p0- ambient temperature. t=0 - time when LED intensity switched to low for IV scans)
- Example, for 100 uA steady current at experiment, T on junction increases ~ 0.6 degrees C above ambient 21.5 C.

- Another approach, measure response. Same method, preheat with LED, switch LED Off, measure response with very low intensity laser. (N.B. different setup, electronics)



- For forward calorimeters more relevant range of current up to 200 uA.



Possible Forward Cal 'gain' change range in one Run.

- This explains what we observed in Run17 (degradation of response with increased leakage current, Slide 3).

SiPMs un-pleasant properties:

a) Response degrades with increased current flowing through SiPM (dark noise due to rad damages + from primary interaction (light from calorimeter), which heats junction). Expect up to 10% change for EIC Forward.
b) It may be large variations across forward calorimeter surface.
c) Possibly, each SiPM will degrade differently.

T compensation in Vbias does not handle this!

T on junction depends on current, which depends on

- location
- luminosity time profile
- integrated exposure
- ambient temperature
- overvoltage SiPM operates at

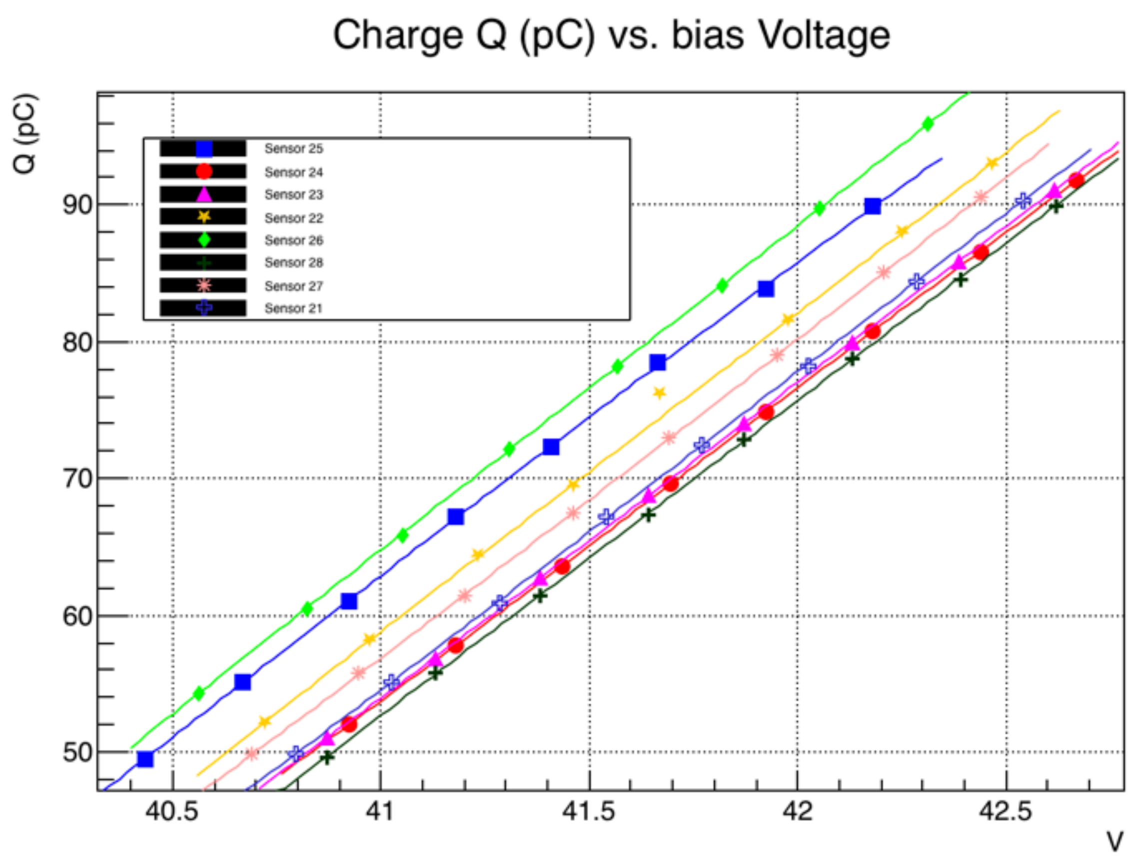
Partial hardware solutions for S12572 type:

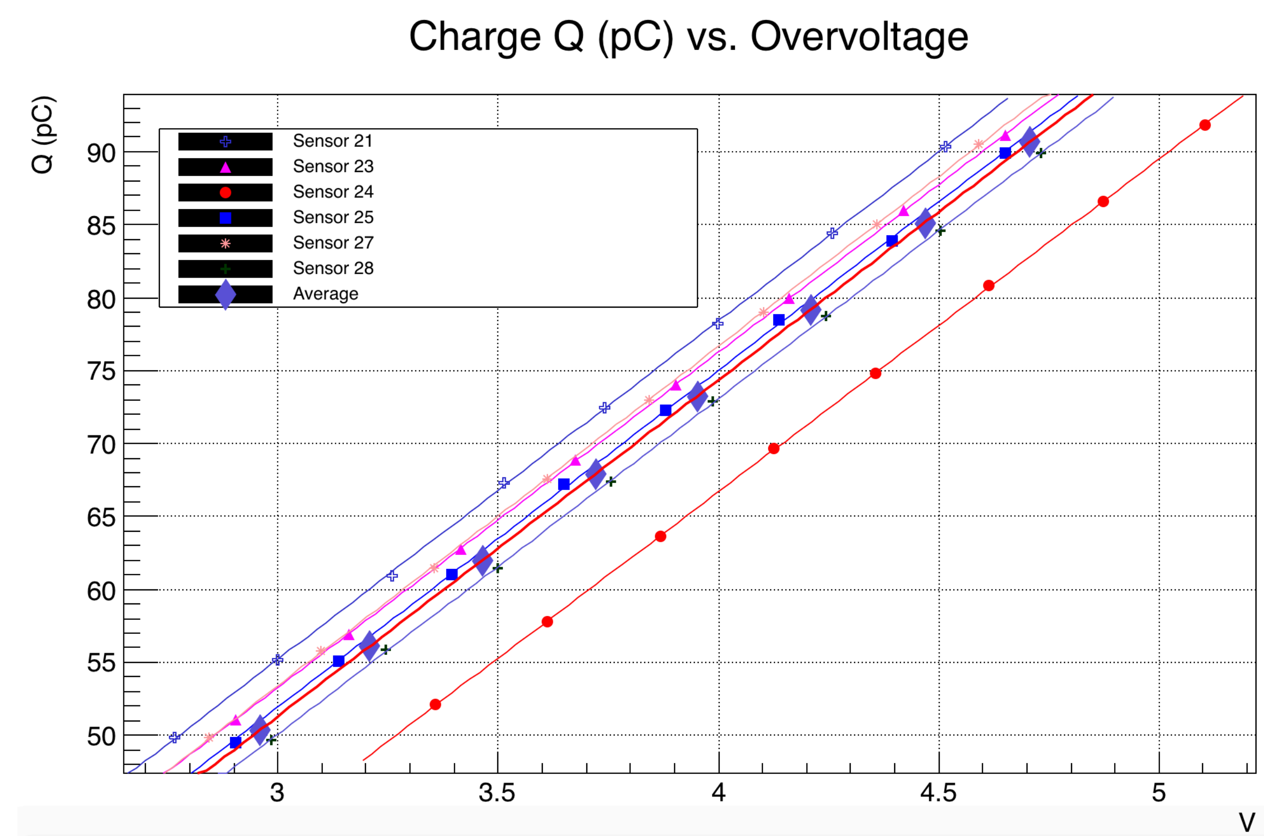
a) Switch to 15 um sensors will help (lower gain)
b) Carefully chose operation bias. (Depends on LY in calorimeter, S/N).
c) Make sure, monitoring (interleaved with data, had to be taken at same average current flowing), i.e. LED runs between fills may not work well).

Efficient cooling for SiPMs, keep delta T (junction ambient) high, reduce leakage current etc. -> lots of complications with integration on the detector.

New HPK sensors, **HDR2-3x3mm-15um** got 8 sensors for tests early summer.
Characterized:

- response vs bias (before/after irradiation)
- Vbd, Vbd vs temperature
- Run similar tests as for S12572-025P, heating with LED – relaxation.

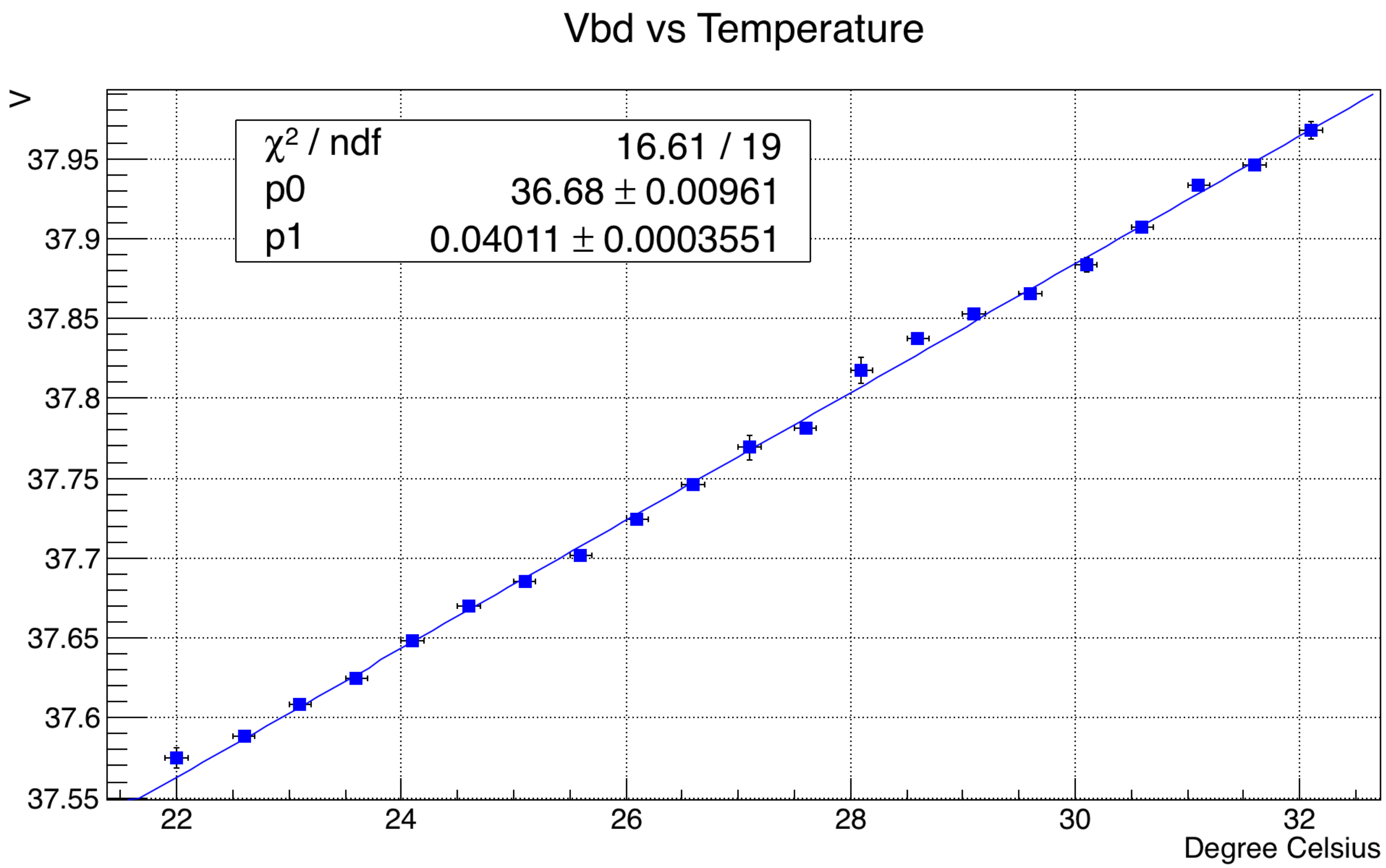




Compare to Old SiPMS:

- Vop is ~20V lower
- Spread from sensor to sensor (overvoltage) to get same response for laser is about the same as for old devices (GlueX has large statistics).
- N.B. this spread possibly is a reason for differential response degradation in Run17 (sensors with same leakage current degrades differently, Slide 3).

- New HPK senasors, HDR2-3x3mm-15um, Vbd vs T – Improved!



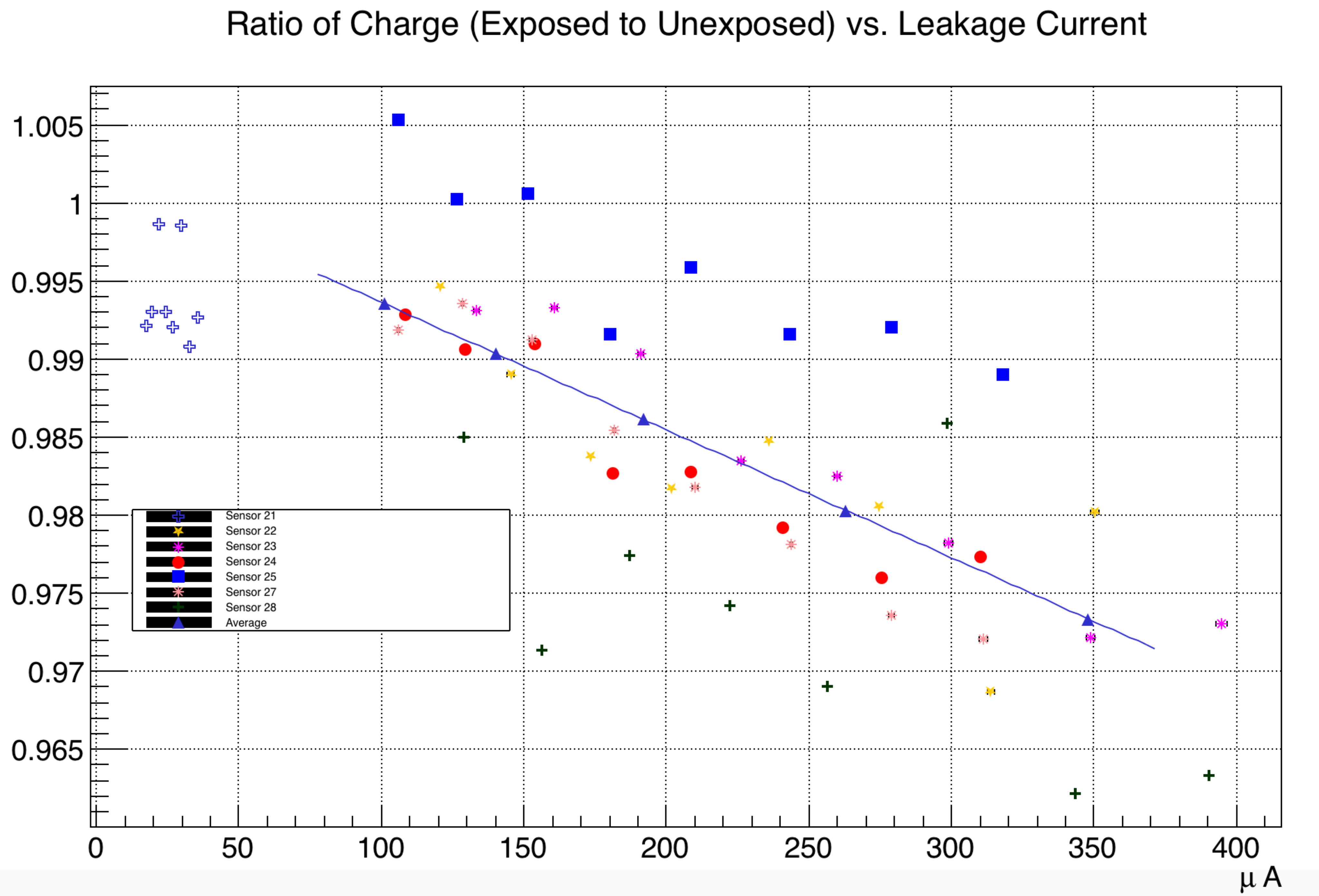
■ Electrical and optical characteristics

(Typ. T = 25 deg. C, Vr = Vop unless otherwise noted)

Parameters	Symbol	S14160 (typ.)				Unit
		-1310PS	-3010PS	-1315PS	-3015PS	
Spectral response range	λ	290 to 900				nm
Peak sensitivity wavelength	λp	460				nm
Photon detection efficiency at λp *3	PDE	18		32		%
Breakdown voltage *4	Vbr	38				V
Recommended operating voltage *4	Vop	Vbr + 5		Vbr + 4		V
Dark count rate	DCR	120	700	120	700	kcps
Direct Crosstalk probability	Pct	< 1				%
Terminal capacitance at Vop	Ct	100	530	100	530	pF
Gain	M	1.8×10^5		3.6×10^5		-
Temperature coefficient of Vop	Δ TVop	34				mV/deg C

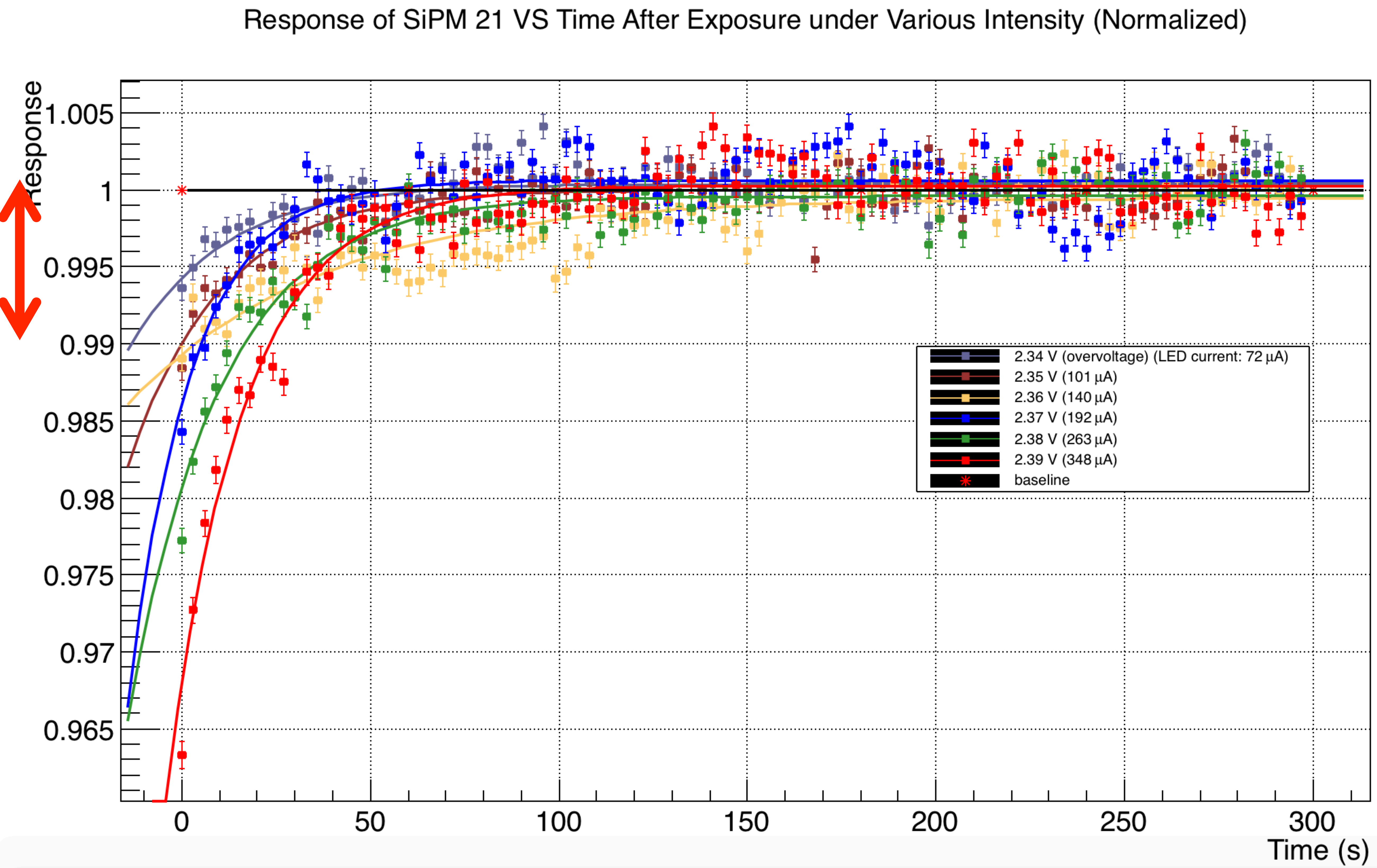
*3 : Photon detection efficiency does not include crosstalk and after pulse.

- HPK released ref. data sheet on Oct 9.
- T dependence is consistent with our measurements.

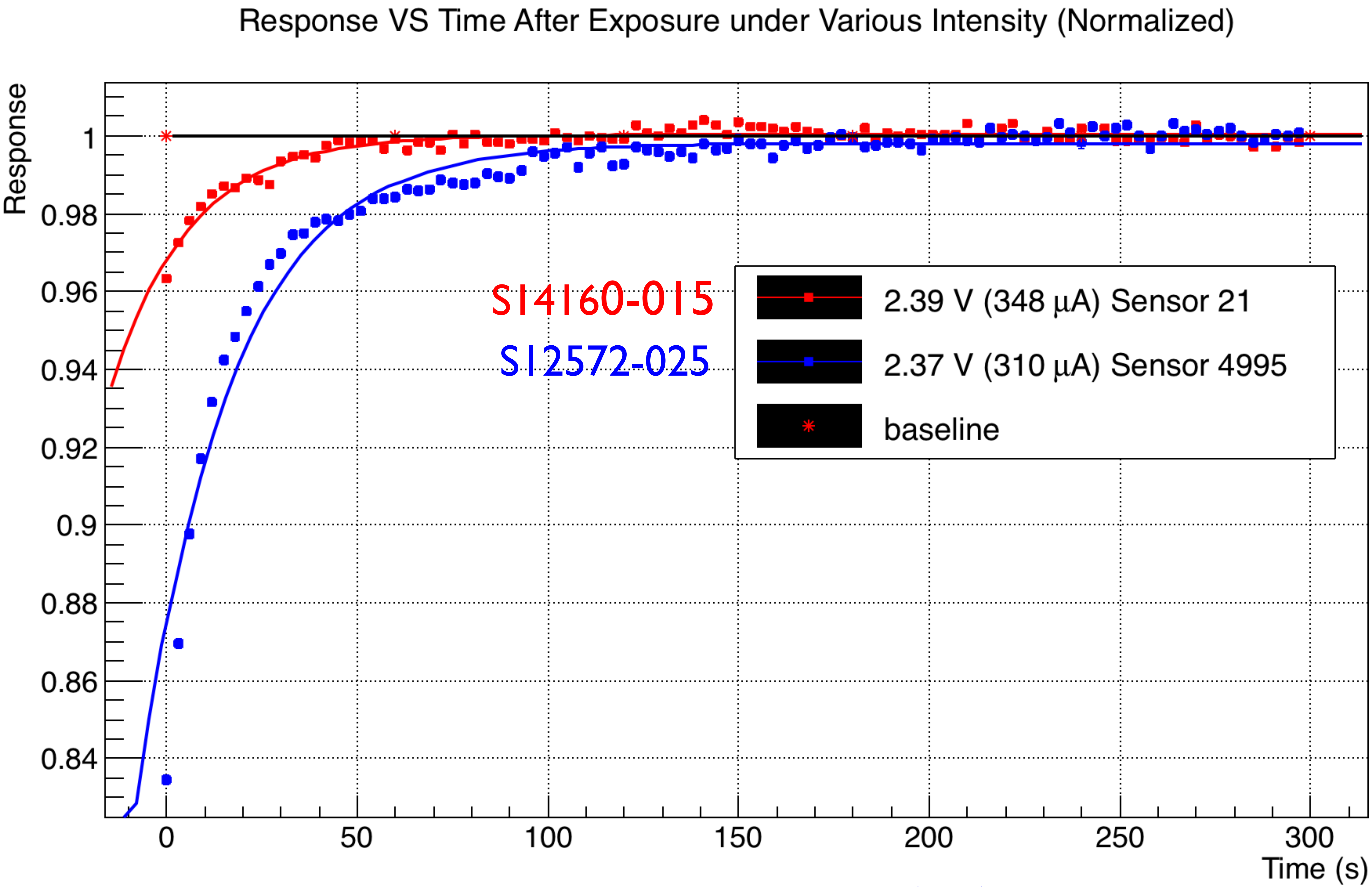


- Sean S. irradiated our 7 sensors at BNL early fall to ~ 7x 10^{10} n/cm^2.
- Response was measured after irradiation and compared to 'golden' un-exposed sensor.
- Much better behavior compare to older version.
- Response drop for old sensors @100uA had drop 6%, new @100uA ~ 1%

N.B. Old sensors 25 um, new 15 um



- Same tests as shown in Slide 8. Much better performance.
- Changes in response due to irradiation relative to EIC forward will be within 1%



Another example, direct comparison of new S141160-015 (#21) vs old S12572_025 (#4995).

Summary

Effects of degradation of SiPMs observed during Run17 have been understood:

- Combination of leakage current (due to radiation damages) and signal current from calorimeter light heats junction of the sensors, which leads to increase in Vbd, which leads to degradation of response.
- Differential degradation (variation from sensors to sensors) probably is due to different overvoltage required to achieve same response.
- New HPK sensors are superior to previous versions. Degradation of response for these sensors due to irradiation at forward rapidities at EIC will be very small (~1% level) for Forward Calorimeter.
- There is a hope that this can be improved in future, for example, SensL SiPMs has even lower T dependence, lower operation voltage as well. And seemingly HPK is moving in this directions (last three generation of SiPMs).